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## **Surgical navigation in craniomaxillofacial surgery: expensive toy or useful tool? A classification of different indications**

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# **Surgical navigation in cranio-maxillofacial surgery. Expensive toy or useful tool? A classification of different indications.**

## **Abstract**

### Introduction

Surgical navigation is well-established in today's cranio-maxillofacial surgery. However, it is often associated with extra effort for both patient and surgeon and with additional exposure to radiation due to necessary extra imaging. The cranio-orbito-facial structures are challenging with respect to accurate three-dimensional (3D) reconstruction. A virtual plan based on mirrored patient anatomy and intraoperative navigation can assist in achieving perfect results. However, in several cases, navigation is not useful. Therefore, the aim of the current study was to evaluate the indications for surgical navigation with the help of various examples.

### Method

Surgeries of the Clinic for Cranio-Maxillofacial Surgery at the University Hospital Zurich between 2003 and 2009 in which surgical navigation was performed or preoperatively discussed were evaluated for typical patterns. Some examples of those cases are presented in regard to evaluation of the spectrum of indications.

### Conclusion

Especially in situations dealing with complex 3D-anatomy, surgical navigation based on a virtual plan can be a great benefit in achieving symmetrical results. Surgical navigation does not necessarily mean additional procedures or imaging.

Overall, we believe that virtual planning and surgical navigation is a useful tool for selected cases.

## **Introduction**

The complex three-dimensional (3D) anatomy and geometry of the human skull and face in combination with the need for precise symmetry poses challenge to reconstructive surgery of the region. Therefore and for technical improvements during the last 10 years or so, surgical navigation is an established technique in cranio-maxillofacial surgery today. [1-4]

Technical problems have been solved and the accuracy of multiple strategies of imaging and registration has been proved. [5] However, the procedure of preparing a patient for navigation is still linked to extra effort for patient and surgeon. Even non-invasive registration procedures, such as, for example, a splint fixed to the upper jaw as described by Schramm et al, need dental impressions and additional imaging with the splint in situ. [6]

Insecurity surrounds the surgical navigation of the lower jaw with different techniques such as mounting a dynamic reference frame to the mandible [7-9] or retaining the mandible in a defined position against the maxilla. [7, 10-15] In conclusion, the state of surgical navigation of the mandible is deemed unsatisfactory at this time. [16]

The aim of this study is to evaluate the feasibility and limitations of surgical navigation. Time and effort of the surgical team are judged in relation to the benefit.

## **Method**

Surgeries of the Clinic for Cranio-maxillofacial Surgery at the University Hospital Zurich between 2003 and 2009 in which surgical navigation was performed or preoperatively discussed were evaluated for typical patterns. Four different groups of typical clinical situations dealt with in the daily routines of cranio-maxillofacial surgery

are presented (Table 1), and from this, a classification of the indications for surgical navigation is derived (Table 2).

#### Group 1, difficult reconstruction

A patient was referred to our clinic with a history of an untreated fracture of the left zygomatic bone. The esthetic result was poor, and therefore, the indication of surgical revision was given. There were no functional symptoms such as double vision or reduced eye motility. Since a single-sided defect situation in complex anatomy is the classical situation for pre-planning by virtually mirroring the healthy side, it was decided to utilize surgical navigation for this patient. Due to the upper jaw being edentulous and the need for precise registration over a large surgical field, six bone screws were implanted under local anesthesia (Figure 1). They were spread over a wide polygon and served as fiducials for registration. [5] Afterwards, a cone beam computer tomography (CBCT) was acquired, serving as a baseline dataset for preoperative planning and operative navigation.

The 3D-dataset was imported into the navigation system (iPlan ENT 2.6, BrainLAB Inc., Feldkirchen, Germany). A semi-automatic threshold segmentation of the healthy right side was performed and manually optimized. The resulting 3D object was mirrored to the affected side and fine positioning was performed manually. Structures not affected by the trauma acted as a reference (Figure 2). The plan was then discussed with the interdisciplinary surgical team within the preoperative briefing.

Surgery started with opening of the necessary coronal approach and fixation of the dynamic reference frame (DRF), which serves to calculate the influence of camera or patient movements on the registration. Landmark checks were done after registration as well as before any surgical navigation. The zygomatic bone was osteotomized and repositioned according to the surgeon's clinical judgment and surgical navigation.

Postoperatively, a CBCT dataset was acquired and data was fused with the preoperative dataset and the virtual planning by semiautomatic fusion, based on unaffected regions of the bone such as, for example, the right orbit, the skull base, and the occiput.

#### Group 2, acute trauma

The diagnosis of severe orbital floor fracture due to trauma is regularly seen. Clinically enophthalmus in combination with double vision in all directions is a typical sign. Eye motility is often reduced. Due to the extent of the fracture and the missing bony margins in some areas a decision was made to employ surgical navigation.

A prefabricated splint that carried the necessary fiducials for point-to-point registration was individualized with impression material (Figure 3) and a CBCT acquired. Planning was performed by mirroring the healthy orbit as described above (Figure 4).

The reconstruction of the orbital floor was done with a titanium mesh through transconjunctival approach and the position of the mesh was adjusted under the control of surgical navigation. A postoperative CBCT was fused with the preoperative dataset and the virtual reconstruction (Figure 5).

#### Group 3, foreign body

Patients suffering from a lingual dislocation of a root segment after an attempt at wisdom tooth removal in the right mandible often are referred to maxillofacial surgeons. Sometimes – as in the presented exemplary patient – an immediate attempt by an oral surgeon to visualize and remove the fragment under local anesthesia has failed. Patient then was referred to our clinic. The initial CBCT revealed the fragment to be in the mouth floor almost directly lingual to the alveolar

socket (Figure 6). Due to the known difficulties with foreign-body removal and the previous unsuccessful attempt under local anesthesia, the decision was made to employ surgical navigation under general anesthesia after an interval of 3 months, which was expected to provide fixation of the fragment inside scar tissue. After 3 months, a positioning splint was designed that fixated the mandible in a defined position against the maxilla and carried fiducials for point-to-point registration (Figure 7). During a short intervention, the fragment was not visualized but localized through surgical navigation (Figure 8) and then uneventfully removed. The postoperative course was uneventful.

#### Group 4, severe trauma without possibility of surgical navigation

As the main trauma center of the region, most serious injuries to the facial skeleton are referred to the University Hospital Zurich. Multi-Slice Computer Tomography (MSCT) is performed regularly. Our clinic is consulted due to severely fragmented and displaced bilateral midface fractures (Figure 9). Orbital walls are affected on both sides. The initial idea of surgical navigation was discarded due to the lack of healthy bone regions that could provide a virtual template. However, after an asymmetric result of the orbital reconstruction, surgical navigation was performed in a secondary correction when the clinically satisfying side did serve as a template. Basically, the case proceeded like a group 2 situation.

## **Results**

Within the reviewed cases, the baseline dataset utilized did change over time, shifting from MSCT to CBCT. When threshold segmentation was performed for extraction of the healthy bone areas, the results based on CBCT required more time-consuming manual, fine work in areas of thin bone, e.g. the orbital floor and the

medial wall. First, because of the imaging technique, the threshold algorithm was less sufficient, and second, because of the higher resolution of CBCT, more slices had to be worked through. The rest of the planning process did not show differences.

### Group 1

The first step of implanting the titanium screws to serve as fiducials later on is not critical. The procedure is done under local anesthesia and performed within about 90 m. The patients do not feel harmed by it. Acquisition of a CBCT dataset afterwards takes about 5 m.

The 3D dataset (DICOM format) was imported into the planning system. Development of a virtual template via segmentation of the healthy side and mirroring were uneventful. Manual, fine work is necessary in marking out orbital walls after segmentation and fine positioning of the mirrored object into its definitive position. A maxillofacial resident performs the total planning process within 150 m. The planning documents are then discussed in a brief meeting of about 15 m the day before surgery. An additional time of 25 m is needed at the beginning of the surgical procedure (system setup 5 m, additional dressing 5 m, fixation of the DRF 15 m).

Before any surgical navigation can take place, the fiducials have to be exposed and a point-to-point matching registration process, including meticulous landmark checks, must be done. This procedure is, again, done by a resident and takes 20 m. The landmark checks performed during the whole surgical procedure revealed exceptionally high accuracy without any measurable discrepancies. The navigational parts of the surgery took about 20 m altogether. Surgical time spared, e.g. due to better orientation and faster reconstruction, could not be quantified objectively. However, the surgeons reported better orientation and relevant help for finding correct symmetry during reconstruction with the navigation and virtual setup.

The postoperative fusion of the datasets takes 20 m and is performed by a resident. Evaluation of the postoperative images was performed in the navigation system and took about 10 m. A high level of consistency between the fused preoperative plan and postoperative CT data was seen.

Double vision is to be expected for about three postoperative weeks and subsides along with postoperative swelling.

### Group 2

Postoperative CBCT showed high accuracy in fulfilling the preoperative planning (Figure 5). Clinically, the patients recovered quickly and after two weeks when the main swelling had subsided, no functional or esthetic impairments were present.

The time required for preparation as well as actual surgical navigation is lower (Table 1) in the acute patients group. Mostly, the 3D situation is easier to assess and the bony edges help a great deal in defining the position of the virtual template.

### Group 3

Foreign bodies represent a small but important group among the surgical navigations. Unfortunately, it is very difficult to predict whether the removal is simple or challenging. The presented patient is typical for this when an initial attempt to remove the root fragment under local anesthesia failed.

Regarding surgical navigation, foreign body removal is simple due to the fact that marking the foreign object is the only aspect of the planning procedure. As a result, planning time is very short. However, data import orientation and marking the fiducials requires a minimum amount of time (Table 1).



In the presented case, due to the object's proximity to the mandible, a special splint had to be provided. Its production is fairly time-consuming and takes about 60 m for the medical staff. The technician's time is added to this.

In this case as well as all other foreign-body removals, we evaluated the surgical navigation itself as fast and successful.

#### Group 4

This group represents patients who were initially discussed for surgical navigation but were not classified for various reasons. Two main reasons were identified: First, there was often a need for fast intervention, with a lack of time available for preparing surgical navigation, and second – and much more often – the situation as presented with bilateral trauma did not allow the mirroring of a healthy side. Under these circumstances, the additional effort required for surgical navigation is often useless because of a lack of benefit.

#### **Discussion**

The baseline dataset changed over the years from CT toward CBCT. This is supported by the literature. [17] CBCT utilizes lower radiation doses than CT [18] and provides high-resolution bone imaging but not soft tissue differentiation. [19] These differences are basically irrelevant because bony structures are navigated in the vast amount of cases. The preparation of the virtual object out of the healthy bone structures required more time if CBCT provided the 3D dataset. However, this difference only occurred if a “nice” virtual template was the goal. “Sloppy” manual, fine work leads to objects with small holes, but in our experience, the surgical navigation is not influenced by this difference.

The utilized registration technique is the key element in the precision of surgical navigation. [20] If preexisting datasets must be utilized, either anatomical landmark registration or laser surface matching are the methods of choice. [5, 21] Since laser surface matching is known to be more accurate, it is the preferred technique. [5, 22-24] Landmark registration might serve as a fallback.

Groups 1 and 2 represent classical indications for surgical navigation, which is mentioned in the literature by several authors. [2, 4] Foreign bodies as presented in group 3 are also indicated by many authors as suitable for surgical navigation. [12, 13, 16, 25]

In group 4, a bilateral fracture situation interfered with the extraction of a virtual template from a healthy region. Prototype concepts exist that utilize a bone atlas – similar to a brain atlas, as described by different authors [26, 27] – with individual size and form adjustment as a solution in constructing a virtual template. However, this is a technique that has to be validated in clinical studies before going into routine use. Therefore, to date, we classify bilateral fracture as unsuitable for surgical navigation (Table 2). However, as in the presented patient, after initial reconstruction, there might be room for improvement, and this is when surgical navigation comes into play again.

Finally, the total time invested by the surgical team preoperatively, as given in Table 1, was very acceptable. In matters of the preoperative briefing time spent, the authors would recommend a briefing for the surgical team. Later, we believe that the time spent for actual navigation during surgery to be more or less compensated by the time saved due to better orientation and fast judgment of reconstruction symmetry.

An overview of our classification for the indications of surgical navigation is given in Table 2.

## **Conclusion**

Following the described classification, we recommend surgical navigation for all Class 1 indications according to Table 2. In Class 2 indications, surgical navigation makes sense if no additional harm is done to the patient with respect to radiation dose or any invasive procedures. In these situations, limitations exist but can be dealt with. Class 3 does not provide any room for surgical navigation. Surgical navigation in the area of the mandible requires meticulous planning but is not contraindicated per se.

We believe that, especially in a growing organism, surgical navigation is a promising concept to achieve accurate reconstruction without alloplastic material, thus avoiding secondary reconstructive surgery.

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## **CONFLICT OF INTEREST**

The authors declare that they have no conflict of interest.

Group	Exemplary diagnosis	Typical preparation	Additional expenditure of time for navigation purposes	Summary
1	<ul style="list-style-type: none"><li>Secondary correction of zygomatic bone after untreated or insufficiently treated trauma</li><li>Edentulous patient</li></ul>	<ul style="list-style-type: none"><li>Implantation of bone screws under local anesthesia</li><li>Acquisition of new dataset</li><li>Virtual template by mirroring</li></ul>	Screw implantation: 90 m  Preoperative planning: 150 m <sup>1</sup>  Surgical navigation: 45m  Postoperative evaluation: 30m	<ul style="list-style-type: none"><li>Situation with maximum time and effort due to edentulous maxilla and need for high accuracy over wide surgical field</li><li>Good clinical outcome to be expected</li></ul>
2	<ul style="list-style-type: none"><li>Acute trauma</li><li>Orbital floor fracture with difficulties of identifying bony edges</li></ul>	<ul style="list-style-type: none"><li>Individualization of prefabricated maxillary splint</li><li>Acquisition of new dataset</li><li>Virtual template by mirroring</li></ul>	Splint preparation: 20 m  Preoperative planning: 90 m <sup>1</sup>  Surgical navigation: 30 m  Postoperative evaluation: 15 m	<ul style="list-style-type: none"><li>Less time-consuming because of smaller surgical field and stable dentition of the maxilla</li><li>Good clinical outcome to be expected</li></ul>
3	<ul style="list-style-type: none"><li>Foreign body close to bony structures</li><li>Lingual displaced root fragment</li></ul>	<ul style="list-style-type: none"><li>Impression and splint construction</li><li>Acquisition of new dataset</li><li>Marking root fragment</li></ul>	Split preparation: 60 m  Preoperative planning: 30 m  Surgical navigation: 15 m  Postoperative evaluation: n.a.	<ul style="list-style-type: none"><li>More time-consuming because of complex double splint technique</li><li>Fast planning process</li><li>Good clinical outcome to be expected</li></ul>
4	Bilateral midface fracture	Decision against primary navigation (surgical navigation can be performed later on when one orbital floor reconstruction is shown to be more sufficient than the other)		<ul style="list-style-type: none"><li>Possibly poor clinical outcome</li><li>Need for secondary correction of one orbital floor</li></ul>
1) Time estimation based on CBCT dataset, faster with MSCT				

Table 1: Overview of typical situations of surgical navigation

Class I	Class II	Class III
Clear indication <sup>1</sup>	Limited indication <sup>2</sup>	No indication
<b>Complex</b> unilateral orbital wall fracture (e.g. missing edges, huge extension)	<b>Simple</b> orbital wall fractures	<b>Bilateral</b> orbital floor fracture <sup>3</sup>
<b>Comminuted</b> unilateral fracture of lateral midface	<b>Simple</b> fracture of lateral midface	<b>Bilateral</b> fracture of lateral midface <sup>4)</sup>
		Fracture of central midface or lower jaw
Bony tumors <b>with</b> <sup>5</sup> <ul style="list-style-type: none"> <li>Expected difficulties in judging the resection margins</li> <li>Relevant structures close to the tumor</li> </ul>	Bony tumor <b>without</b> <sup>5</sup> <ul style="list-style-type: none"> <li>Expected difficulties in judging the resection margins</li> <li>Relevant structures close to the tumor</li> </ul>	Soft tissue tumors <sup>2</sup>
Bony reconstruction in complex 3D-anatomy <sup>5</sup>	Bony reconstruction in simple 3D-anatomy <sup>5</sup>	Soft tissue reconstruction
Foreign bodies in the bone <sup>5</sup>	Foreign bodies in the close bony structures <sup>5</sup>	Foreign bodies in the soft tissues
1) Surgical navigation should be performed. 2) Surgical navigation can be performed if no additional procedures are necessary for preparation. 3) Indicated in clinical studies with evaluation of (individualized) atlas-based virtual reconstructions. 4) Indicated in extensive technical setup with additional data, e.g. operative ultrasound or operative MRI. 5) In the lower jaw only if fixation of the mandible against the maxilla in the same defined position is feasible for preoperative data acquisition and surgical navigation.		

Table 2: Classification of indications for surgical navigation

Figure 1: Titanium screws serving as bone anchored fiducials spread over a wide polygon for maximum of accuracy over a large field.

Figure 2: Healthy side mirrored to affected side serves as virtual plan (green)

Figure 3: Prefabricated splint carrying fiducials for point-to-point registration after individualization with impression material

Figure 4: Virtual reconstruction of the orbital floor by mirroring the orbital bone structures of the healthy side.

Figure 5: Postoperative evaluation through fusion of preoperative plan and postoperative control CBCT

Figure 6: lingual displaced root segment after wisdom tooth removal (detail out of CBCT)

Figure 7: Individual splint for positioning mandible against maxilla for preoperative data acquisition and surgical navigation (also carrying fiducials for point-to-point registration)

Figure 8: Localization of the root fragment without open visualization

Figure 9: Bilateral midface and orbital wall fracture without healthy side that could serve as a virtual template

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